Agent-based Modelling: What Matters is Action

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Abstract: Computer-aided management tools or models of production systems in the manufacturing or agricultural domains generally rely implicitly on the theory of planned action. Every action is assumed to be part of an anticipated sequence leading from a current state to a predetermined goal. The main limits of this classical view are due to the difficulty to deal with unexpected changes and disturbances. To overcome these limits, we developed an agent model based on the theory of situated action. Whereas the classical approach puts the emphasis on actor's decision (action being assumed to straightforwardly follow), situated action is viewed as a process endowed with a temporal thickness, spontaneously emerging from the situations created by the local interactions between the actor and its environment. This model, accounting for both the temporal and spatial dimensions of action as well as its contingent features, implements the concepts of affordance (capacity of objects to trigger actions) and stigmergy (self-organization mediated by marks left by individuals in their environment). Therefore we propose a multi-agents system where the perspective is reversed compared with the usual view: in our model it is the environment which is agentified and, so, endowed with the capacity of acting by handling the entities it contains. Unlike in classical multi-agents systems, these entities (standing for humans, animals…) are, actually, considered as non-autonomous and passive. After advocating our choice to put the emphasis on action rather than on decision to represent actual human activity, we explain the concepts of affordance and stigmergy and outline the non-classical multi-agents system we devised with the perspective to simulate agricultural production systems.

Keywords: planned action; situated action; affordance; stigmergy; multi-agent systems.

1 INTRODUCTION: ACTION-CENTRED MODELLING OF HUMAN ACTIVITY

Since the 1950's with the early applications of emerging Operations Research methods in the firms, the emphasis has mainly been put on decision: every action is assumed to stem from decision-making by a (often unique) rational decision-maker, even though the notion of rationality has evolved from mere optimisation to the search for a 'satisficing' solution (Pomerol, 2002). Applied to operations management this approach posits the centrality of a 'plan' as a representation of sequences of actions to be executed to attain a goal (Miller, 1960). Managing comes down to generate and control the plan execution on the basis of sensed data to reduce the discrepancies between planned and actual actions. This stance, largely dominant in the Western culture and, so, in various research fields (cognitive science, artificial intelligence, robotics, management…), has inspired various computer-based tools to support the management of manufacturing systems (Johnston and Brennan, 1996) and to design information systems (Johnston et al., 2005). Also, until recently, the management and human aspects have not often been adressed in farming system modelling or, when it were the case, the same decision-driven/planning approach prevailed (McCown, 2002; Garcia et al., 2005; Martin-Clouaire and Rellier, 2009).

However, this 'deliberative' theory of action has been criticized by many authors (Suchman, 1987; Johnston and Brennan, 1996; Clancey, 2002). In effect, the analysis of human activity at operations level actually shows that, if the plan is a common representation to talk about action (i.e. to analyse, prescribe, justify it; Javaux, 1996), actual activities rely only partly upon using plans but, rather, on implementing a great variety of ad hoc behaviours spontaneously generated in response to the actual situations the agent is engaged in: routines, adaptive cultural patterns, distributed sensori-motor coupling. Those behaviours do not necessitate, neither conscious representation, nor reasoning, nor decision making (Cohendet and Diani, 2005). As quoted by Clancey (2002): "All human activity is purposeful. But not every goal is a problem to be solved and not every action is motivated by a task". As an alternative to the dominant theory of planned action these authors proposed in the late 1980's the theory of 'situated action' (Suchman, 1987). Managing, here, consists mainly in structuring the physical and organizational environment of action to foster adaptive behaviours of the agents, embodying their routines in the real world (Hirose, 2002; Cohendet and Diani, 2005), while avoiding as far as possible those situations where they must have recourse to decision making through deliberation (Johnston et al., 2005). The decisional paradigm of Management Science and Operations Research thus appears shifted with respect to most actual working practices. This could explain why numerous users in manufacturing (Johnston et al., 2005) as well as in agriculture (see the description by McCown, 2002, of the "problem of implementation") are reluctant to adopt these tools.

But in agricultural systems, our application field, sustainability is obviously strongly dependent upon farming practices. If one wants to assess the former, one needs to focus on the latter. Due to the inherent complexity of such systems, made of numerous interacting components, the recourse to modelling is unavoidable. Our research, therefore, aims at building a modelling framework to represent human actions and their impacts to help assess farming practices. After a first approach based on systems dynamics that dealt with action in the temporal domain (Guerrin, 2009), we have recently developed a novel approach based on multi-agents modelling. Using the concepts of 'affordance' and 'stigmergy' this model integrates the spatial and agent dimensions of action (Afoutni, 2015). It is this second piece of work which is presented hereafter.

2 PLANNED VS. SITUATED ACTION

Management issues are classically formulated as planning and decision problems. This is due to the widespread conception, stemming namely from standard economy (Cohendet and Diani, 2005), that human actions necessarily require some kinds of representations like plans to decide at every time what to do next: "Planning is the reasoning side of acting" (Ghallab et al., 2004). Planning is so a deliberative process enabling one to select and organize a set of actions based on their expected outcomes. The output of this process is a plan, defined by Miller (1960) as "any hierarchical process (…) that can control the order in which a sequence of operations is to be performed". This definition emphasises two features of a plan: its hierarchical structure and its role to control action. Action is defined by its preconditions, its effects and its possible decomposition in sub-actions (Allen, 1984). According to this planning theory:

- Every actor has a goal, predetermined and stable, viewed as the state of the world to attain;
- A 'plan', symbolic representation of a sequence of actions, is generated to reach the goal;
- Acting means executing the plan as a program, more or less flexibly to account for the actual conditions encountered during its execution;
- The actor is viewed out of the environment which does not provide any help and is, at worst, hostile (source of constraints and uncertainties) or, at best, neutral (stable and previsible);
- Action stops when the goal is reached;
- Managing consists in generating the plan and controlling its execution to minimize the discrepancies between anticipated and realized actions.

Away from this deliberative theory viewing action as problem solving (Pomerol, 2002), analyzing activity systems in many domains has demonstrated that a very large part of human activity is essentially reactive. According to the theory of 'situated action' (Suchman, 1987) in effect:

- Every actor, moved by various motivations, often aims more at maintaining his/her relation with the environment (including other actors) or a subjective internal state (e.g. satisfaction) than to reach an objective state; the 'goal', when explicited, is evolutive, contingent and often elaborated during the course of action itself: "the unequivocal pursuit of objectives (…) is very much the occasional special case; it is certainly not the norm" (Checkland, 1999);
- There is no need of formal centralized representation of the activity to perform; even (partial, coarse) plans may be used as resources to guide action, but never determine it completely;
- Acting means implementing a great variety of ad hoc behaviours in response to the situations the actors participate: routines, cultural or adaptive schemes, distributed sensorimotor coupling…, all necessitating neither representation, nor reasoning, nor decision-making;

- Action never stops (sleeping, resting are still activities) and self-maintains dynamically: situations create actions and actions contribute to create new situations; plans and goals are actually emergent features of action but are not decisive;
- Actors are continuously interacting with their environment structured by their practices; this help them alleviate their cognitive burden, co-ordinate and adjust their activity in real-time;
- Managing means structuring the environment by creating ‘affordances’ (Gibson, 1979; Reed, 1996) to guide actors’ adaptive behaviour and avoid the situations where they must decide.

Our objective is to contribute to this theorizing endeavor about action simulation modelling through the design of a simple formalization, based upon a limited number of concepts (i.e. an ontology), to allow the structure of action to be represented and analysed in its dynamic and spatial dimensions, its functioning in real settings to be understood and improved management policies to be devised.

3 REPRESENTING ACTIVITIES AT OPERATIONS LEVEL

The modelling framework of action we devised is based on the situated action theory for two reasons. Firstly, it is linked to the object of our modelling endeavour. If we aim at modelling whole-scale farming systems, making action rely on a single global plan (or a bundle of partial plans) is clearly unattainable due to the inherent complexity of planning itself. Actually, existing farming systems simulators ignore this crucial step. The plan is often made ‘manually’, based on expertise, and used as a fixed, a priori determined, model input (e.g. in Martin-Clouaire and Rellier, 2009). This comes from the difficulty to generate or revise a plan in due time for acting (Jennings et al., 1998). Questioning the planning concept is also unavoidable with a theoretical viewpoint: if every activity needs a plan, so is the planning activity itself as well as the planning of planning and so on. Until which Great Planner should we go to comply with the plan absolutism? Secondly, it is linked to the expected uses of our models. If we want to assess by simulation agricultural production systems with respect to sustainability, it is by representing as accurately as possible what is (or will be) done in practice that we can measure their impacts (performances, resource consumptions, emissions of pollutants, etc.) and, reciprocally, assess the influence of possible changes on the farming activity. Taking an a priori defined plan as determining action, would be taking a static reference to account for an intrinsically dynamic system based on the interaction between actors and the environment.

Therefore it is the operations level of management our models must reproduce being prioritarily focused on action, immanent and dynamical, rather than on decisions and plans, transcendental and static. This recalls Brooks’ stance (1991): "representations are not necessary and appear only in the eye or mind of the observer". But it is at the tactic or strategic levels, at which decisions are made, these models should be used. Otherwise said, if the model must represent virtual agents’ actions at the operations level, it should be used to support real actors’ decision-making at the tactic or strategic levels. Eventually, the dialectic opposition between planned and situated action matches quite well the distinction made by Aristotle between ‘praxis’ (i.e. action for itself) and ‘poiesis’ (i.e. action for reaching a goal). Hence, our role should be, by representing actors’ praxis at operations level, support the poiesis of decision-makers at the strategic level. Although, both functions are actually exerted by the same individual in a classical farm (the farmer) they should conceptually be distinguished.

4 THREE CONCEPTS FOR REPRESENTING ACTION AT OPERATIONS LEVEL

4.1 The Concept of Situation

Hence, we have based our model on the situated action theory. Every action is situated both in time and space and modelled as a dynamic process evolving with the actor’s situation. It is endowed with starting and ending dates, a duration and location. Action influences the situation that triggered it. It is not frozen but changes adaptively because of its realization. The situation refers to the information sensed and interpreted by every actor. A situation is the whole set of resources and constraits playing a role to guide actors’ actions. Thus it is not reduced to a set of mental images (Visetti, 1989) though it has a subjective aspect: several actors do not necessarily perceive the same setting similarly. For Lave (1988), every situation combines two elements: the actor’s spatial environment (the objective part called ‘arena’) and the actor’s perception (its subjective dimension called ‘setting’).

4.2 The Concept of Affordance

The concept of affordance has been popularized by Gibson (1979) in his theory of direct perception in ecological psychology (see also Reed, 1996). For Gibson, when an actor perceives objects or events in his/her environment, he/she automatically understands the possibilities of action they afford. This concept has motivated a lot of research to make clearer whether affordances were intrinsic properties of the environment or, rather, emerging features from the actor-environment coupling. Turvey (1992) defined an affordance as a 'dispositional' property of the environment. That is, action is triggered only if the actor owns the 'dispositional effectivity' to complement the object's property. This definition, however, has been criticized by authors like Chemero (2003) and Stoffregen (2003) for whom an affordance does not belong to the environment or the actor but is a contingent relationship possibly emerging from the interaction between the actor's capacities and the environment's characteristics. We stick with this latter definition. For us, an affordance emerges from the agent-environment coupling and situated in time and space. But it is only a possibility of action (necessary condition). The corresponding action is realized iff all other conditions for its occurrence are satisfied.

4.3 The Concept of Stigmergy

Stigmergy has been coined by Grassé (1959) studying social insects. He demonstrated the control and coordination of actions in termites building their nest do not depend upon themselves but on the building itself. Each individual's actions are thus guided by the result of actions made by the community. Stigmergy is thus an indirect form of communication mediated by local changes made by the actors in their environment. There exist two forms of stigmergy: the one based on actors' realizations like in termites (called 'sematectonic'); and the one based on marks left by the individuals. We considered only this latter form of stigmergy based on marks which classical example is ant colonies (Deneubourg et al., 1990). Foraging ants start moving randomly to explore the environment around their nest while dropping pheromones. When an ant finds food it brings it back to the nest following the marks already left which are reinforced by its continuous droppings. Being attractive, these marks will foster other ants to follow the path to food they will, in turn, reinforce by new droppings. The stability of the path between the nest and the food source depends on the ants' traffic. When the food source progressively becomes exhausted, the path is less and less followed and, as pheromones evaporate, becomes less and less attractive to ants until it vanishes. Although humans are obviously not social insects, stigmergy is deemed relevant to account for human activity (Christensen, 2013). Heylighen (2016) considers even it a universal mechanism for enabling "complex, coordinated activity without any need for planning, control, communication, simultaneous presence, or even mutual awareness".

5 A MODEL OF SITUATED ACTION.

5.1 Environment

We have exploited the little classical idea of the environment endowed with an intelligence enabling it to pilot the entities it encompasses to make them act. The physical space is a 2D continuous space partitioned into a set of cells (called 'places') with regular or irregular shapes forming a grid (Fig. 1). On this space are located a set of 'environmental entities'. We distinguish two types of entities whether passive or active. Passive entities are the ones that can just undergo actions. For example, a food stock can undergo being filled or emptied. Active entities are those that can be used for acting. The operational coupling of active entities forms what we call an 'actuator'. Actuators are

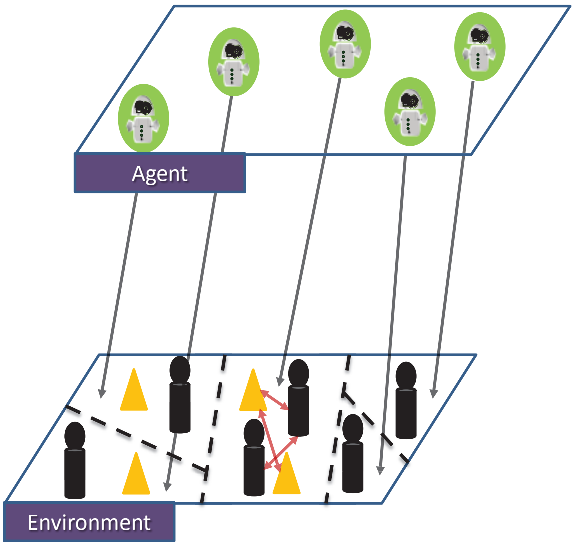

Figure 1. Model architecture: environment layer made of a 2D physical space partitioned into places holding environmental entities; every place is supervised by one abstract agent.

the actual action performers. They are endowed with the capacities to execute action although they cannot decide to act by themselves. This role is assigned to the 'place-agents' controlling the places on which entities are situated (see §5.2). For example, the action of ploughing can be realized with an actuator made of the 'farmer-tractor-plough' entities coupled together by the place-agent controlling their place. An actuator thus differs from an agent as it lacks autonomy. It can only execute the actions ordered by the place-agent it depends upon. An environmental entity thus can play a role of passive object or actuator according to its situation. But, whatever their role, they all contribute to the emergence of the affordances leading to actions that will be performed by the actuators (see §4.2). These entities have attributes to describe their state and internal processes. Actuators, in addition, have processes standing for the actions they perform and, so, affecting the environment.

5.2 Place-agents

The physical space and the environmental entities are controlled by abstract situated agents called 'place-agents' (Fig. 1). Their role is to detect, thanks to the rules they hold, the affordances possibly emerging from the interaction between the environmental entities located on their place and, whenever possible, trigger the appropriate actions in the corresponding actuators. A place-agent is equipped only with the rules corresponding to actions likely to be executed on its place (the actions to be made on a crop plot are not the same than in a cattle workshop). But it may happen that various actuators emerge and, so, many candidate actions appear on the same place. To select the action to be executed, the place-agent uses the priority rank associated to every action. Beyond its own place, a place-agent can also perceive other places comprised in its perception field. It can thus possibly also detect affordances emerging from entities located at its neighbours without being able to order them to act. When this happens, the place-agent exhibits its interest by the means of stigmergy (see §5.3). The fact a place-agent can only order the actuators located on its place, made possible by the space partition, thus avoids the conflicts that would arise when ordering the same actuators by neighbours. Finally, the behaviour of every place-agent is as follows:

- At each time-step, detect the affordances from the set of perceived entities;
- Select the affordance corresponding to the action with highest priority;
- Check whether the remaining conditions to execute this action are satisfied;
- If so, trigger the chosen action in the corresponding actuator.

Once realized the action will impact the state of its place and of the environmental entities present. The place-agents are thus 'situated' as they sense and act locally. This contrasts with classical approaches where, unrealistically, agents possess the whole knowledge of the world.

5.3 Agent Coordination Based on Stigmergy

If a place-agent moved by the affordances it detects has no need to coordinate its own actions, affordances do not suffice to coordinate a community of agents. For this, stigmergy is used. Place-agents coordinate with others based on the marks they drop on their place. Perceived marks are constitutive of agents' situation. Two types of marks are distinguished: flags and traces.

Flags are marks that do not spread in the environment. They are used by the place-agents to communicate with their neigbours. For example, let us assume a place-agent is ploughing its place using a farmer-tractor-plough actuator and a neighbour is afforded by the farmer-tractor actuator to execute another action (e.g. transport). In that case the latter will exhibit its interest by hoisting a flag on its place. Flags hold two attributes: the identifier of the aimed entities (here farmer-tractor) and the priority of the intended action (here transport). If the priority rank of transport is higher than of ploughing, the farmer-tractor actuator will be sent to the demander's place. Otherwise it will keep on ploughing. In either case, the demanding place-agent will put its flag down: either because its demand has been satisfied, or because the farmer-tractor actuator has gone out of its perception field and the corresponding affordance has vanished.

In contrast with flags, traces are spread over the environment, allowing remote place-agents unable to perceive themselves to communicate. Depositing a trace by an agent on its own place can be triggered by three stimuli: (i) the interruption of an ongoing action due to the lack of a necessary resource; (ii) the demand of an action needing to be performed some unknown actuator to be sent from outside; (iii) the perception of a trace on a neighbouring place to be propagated in case a response cannot be made. The validity of the information held by a trace evolves over time. It is thus necessary to update it when it becomes obsolete:

- Instantaneously: when the demanded action has started, the demanding place-agent erases the trace it made, leading its neighbours with the same trace step by step to do the same;
- Progressively: when the traces propagated during a search for a missing resource or actuator did not find their aim, their lifespan is decremented at each time-step until it vanishes.

5.4 Model implementation

The model has been implemented with AnyLogic, a multimodelling platform bringing together systems dynamics, discrete events and multiagents representations. Fig. 2 displays a simulation interface featuring two farms. In its center is the physical space partitioned into places of different kinds: crop plots (farm1 green, farm2 red), warehouses (yellow), livestock buildings (purple), roads (grey), houses (black). A list of detected affordances is in the window to the left. Various actions can be simulated among which plot disinfection and feeding animals are represented on the two graphs at the bottom of the right panel. They display the time evolutions of actions as binary processes (1: action on; 0: action off). Stock evolutions are in the topmost graph. The spatial dimension of actions appears as different shades of colours of the crop plots, contrasting thei(r treated vs. untreated parts.

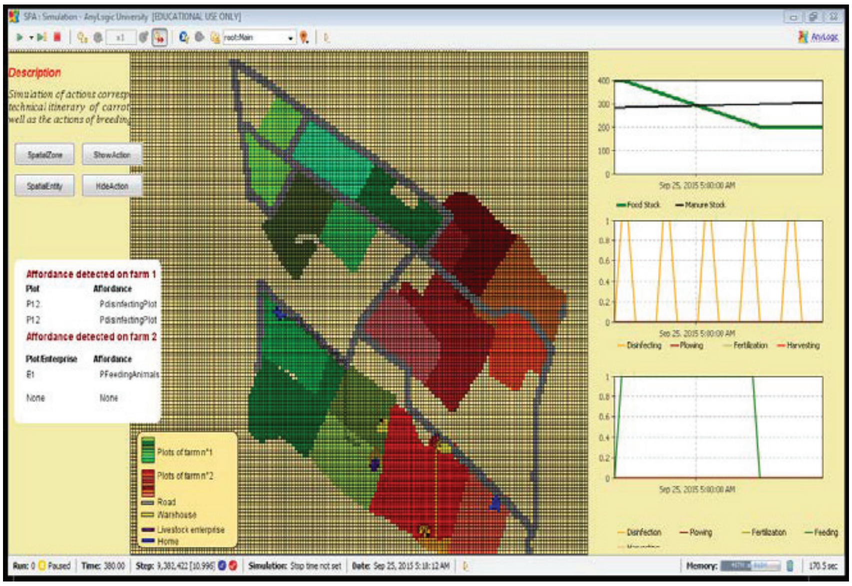

Figure 2. Model interface displaying the case of two farms (see text).

6 CONCLUSION AND PERSPECTIVES

The modelling framework outlined in this paper can compare nicely with other authors' work: Allen's theory of action and time (Allen, 1984), ontology of action in production systems (Grüninger and Pinto, 1995), the Brahms agent-based model to simulate human activities (Sierhuis, 2001) and, since it was our starting point, the theory of situated action (Suchman, 1987). It satisfies many requirements deemed necessary by some of these authors to represent action as a process embodied in the real world and, so, situated in time, space and society (Suchman, 1987; Sierhuis, 2001; Clancey, 2002).

Our model is built with three main components: the environment made of a physical space and environmental entities, embedded agents and the marks they deposit. The originality of this approach is to endow the environment with capacities of triggering and controlling actions.This stance is in keeping with the situated action and the affordance concepts. It is also coherent with psychology famous experiments by Stanley Milgram at Yale in the 60's (see the movie 'Experimenter' by Michael Almereyda, 2015) suggesting the human propensity to behave following external pressures. Human action stems from a continuous dynamical interaction between the agents and their environment. However, as it has been conceived dynamical, our model of action clearly departs from the static approaches actually aimed at reasoning about already made actions rather than representing ongoing actions. This is the case of approaches based on variants of predicate logics (see the synthesis on temporal reasoning in Artificial intelligence by Chittaro and Montanari, 2000) like situation calculus (Grüninger et Pinto, 1995), temporal logic (Allen, 1984) or event calculus (Kowalski and Sergot, 1986). However similarities may be found: for example, we translated into a dynamic representation, Allen's static temporal relations. Relying on similar features (constraints of temporal order, extension, duration…)

our model could undoubtedly allow one to simulate dynamically Javaux's (1996) formalization for task analysis.

Conceiving the environment as an intelligent entity directing action enables easily to implement the concept of situatedness. However this does not imply the model can simulate the most appropriate actions. Otherwise said, it is not aimed at optimizing working flows but, rather, at proposing a pretty much realisitic representation of what can occur in the reality where optimization is scarce, which was actually our objective. In our system intelligence is distributed over numerous simple agents rather than concentrated within a limited number of smart, cognitively complex, ones. Agents' behaviour, based on affordances, allows them to adapt to the changes occurring in their environment without calling for complex algorithms (e.g. replanning). The use of stigmergy based on marks allows the agents to coordinate implicitly. This also preserves agents' flexibility and versatility. Finally, we believe this model can represent human action in farming systems in a relatively realistic fashion. In effect, it is generally observed in this domain behaviours guided by the strong interaction between the actors and their local environment. This may be the case in many other domains too. In the next phase of this work, we envision to apply our representation framework to real complex farming systems involving lot of plots, roads, entities and activities interacting in a common territory.

In contrast with what implies more or less explicitly the planned action paradigm (Garcia et al., 2005) according to which every action stems from a decision, we believe decision and action are not miscible or interchangeable: "decisions do not always lead to actions, whereas actions are not always preceded by decisions" (Urfalino, 2004). Our model, focusing on action as such, meets the Checkland's (1999) wish: "modelling purposeful human activity systems as sets of linked activities which together could exhibit the emergent property of purposefulness." If a plan denotes obviously an intention, intention may as well be considered, not as a premise of action, but as its result (Livet, 2005).

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